EVALUATION OF PEDESTRIAN PROTECTION STRUCTURES USING IMPACTORS AND FULL-SCALE DUMMY TESTS

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Paper No.271

ABSTRACT

Pedestrian protection technology has drawn considerable affection. Three sub-system tests have been proposed by EEVC/WG17 to evaluate car front aggressiveness: 1) legform to bumper test, 2) upper legform to bonnet leading edge test and 3) headform to bonnet top test. In addition, a pedestrian full-scale dummy has been developed to evaluate the kinematics of a pedestrian. However, the differences between the sub-system tests and the full-scale dummy test have not been clarified yet.

The object of this study is to clarify the differences by comparing the results of sub-system tests and full scale dummy tests on the same impact condition in a compact car.

A typical compact car was selected and several kinds of car front specifications were implemented. A series of tests with combination of two impact speeds, 25 and 40km/h and several car front specifications was conducted using three impactors proposed by EEVC/WG17 and a full-scale dummy. A POLAR dummy developed by Honda R&D Co., Ltd. and GESAC was used.

The kinematics was compared by video analysis. The head accelerations, the accelerations and loads of femur, leg and others were compared by electronic measurements. It is clarified how the results of sub-system tests and full-scale dummy tests have been influenced by the difference of impact speed and car front specifications. And its reasons were discussed as well.

INTRODUCTION

Figure 1 shows the distribution of fatalities for different type of traffic accidents in Japan, 2000. (ITARDA 2000) Fatalities related to pedestrian accidents contribute to 28% of total traffic accident fatalities, second next to car occupants. Therefore, improved protection of pedestrians is desirable. Figure 2 shows the injury distribution of each body region for fatalities and injuries. (ITARDA 2001) The percentage of head and face injuries for fatalities is the highest and accounts for 60% of all regions. For serious injuries the percentage of leg injuries is the highest and accounts for 50% of all

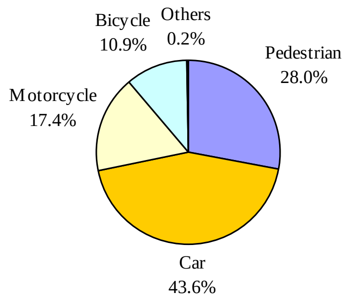


Figure 1. Distribution of impact type for fatalities

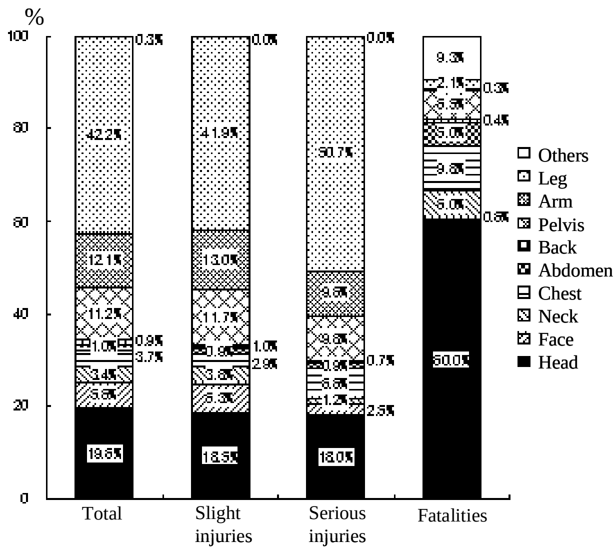


Figure 2. Distribution of body region for fatalities and serious injuries

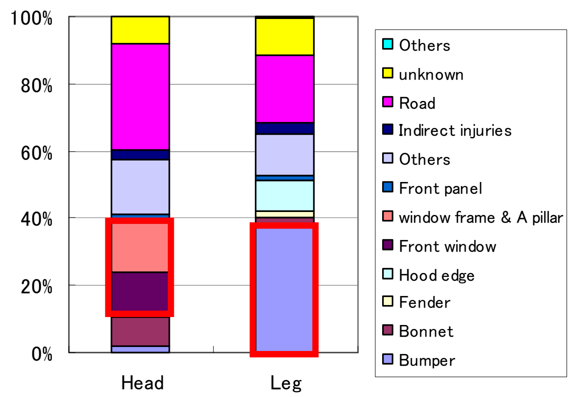


Figure 3. Distribution of impact parts for head and leg injuries

regions. Figure 3 shows the distribution of impact parts that cause injury to head and leg. (ITARDA 2001) The window, window frame and A-pillar contribute to 30% of total head injuries. The main cause of leg injuries is the bumper, which contributes to 40% of total leg injuries. Therefore it is important to consider the collision between head and window, window frame and A-pillar and the collision between leg and bumper for pedestrian protection.
About 7000 pedestrians per year are killed by traffic accidents in the European Union. (Davies 1997) For this reason, the European Enhanced Vehicle-safety Committee (EEVC) has proposed test procedures to evaluate vehicle aggressiveness against pedestrians. The procedures were implemented by EURO-NCAP. Many vehicles on the market were evaluated according to these procedures and the results are publicized. The procedures focus on subsystem tests because of low cost and high repeatability compared to full-scale pedestrian dummy test. (Harris 1989)
Figure 4 summarizes the set-up of the subsystem test procedures proposed by the European Enhanced Vehicle-safety Committee/WG17 (EEVC/WG17 1998). Three different impactors representing head, upper leg and whole leg are impacted against the car bonnet, bonnet leading edge and bumper, and the accelerations, loads or others of the impactors are evaluated.
In addition, full-scale test dummies and mathematical models have been developed to evaluate the kinematics of a pedestrian. (Akiyama et al. 2000, G.Coley 2001, M. Howard 2000) The relationship between subsystem tests and full-scale dummy tests is not clear and a lot of attention is paid to understand the differences. Japan Automobile Research Institute (JARI) conducted the comparison between subsystem tests and full-scale dummy tests using two different types of vehicles, a compact car and a sport utility vehicle. (Matsui 2002) However the evaluation of different impact speeds and pedestrian protection structures using the same car has not been studied.
The first object of this study is to evaluate the impact test results between sub-system and full-scale dummy in a compact car. On a condition of two different impact speeds, four car front specifications are implemented as countermeasures for pedestrian protection. The second object is to clarify the effect and problems of the applied countermeasures.

METHODS

EEVC subsystem tests (head, upper leg and leg) were conducted at Mazda and full-scale dummy tests were conducted at JARI. Impact speeds are 25 and 40km/h. A production car was used and its main specifications are shown in table 1. Four types of specifications for pedestrian protection were applied. The center of the bumper was selected as the impact location for the leg impactor tests, the upper leg impactor tests and the full-scale dummy tests.

Subsystem tests

Legform-to-bumper test - Figure 5 shows the legform-to-bumper test. The vehicle cut-body was fixed to the ground. A legform impactor developed by the Transport Research Laboratory (TRL) (Lawrence et al. 2000) was used as test device. The tibia acceleration, knee shearing displacement and knee bending angle were measured by sensors commercially equipped into this impactor. The data were sampled at 10kHz and processed by means of an SAE 180 filter. The motion of the legform impactor was recorded by high-speed digital camera (1000 frames/second).

Upper legform-to-bonnet leading edge test - Figure 6 shows the upper legform-to-bonnet leading edge test. The vehicle cut-body was fixed at the

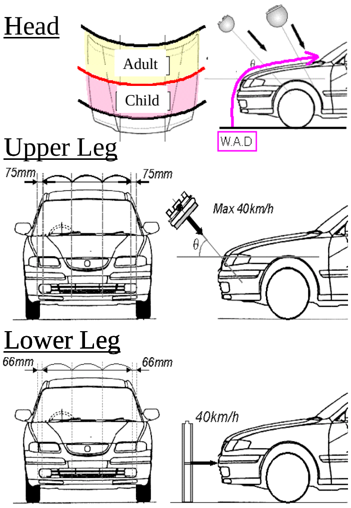


Figure 4. EEVC subsystem tests

Table 1. Vehicle specifications

Total length – total width – total height (mm)	4670 - 1780 - 1430
Minimum height (mm)	135
Weight (kg)	1340

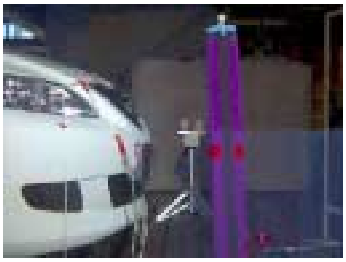


Figure 5. Legform impactor test

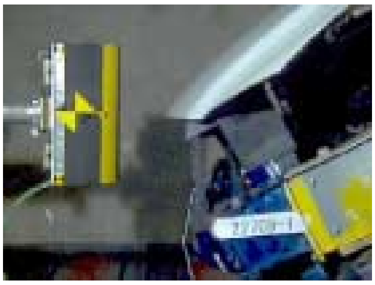


Figure 6. Upper legform impactor test

Table 2. Upper legform impact conditions

Imact energy	J	510
Impact speed	m/s	9.5
Impactor mass	kg	13.17
Impact angle	degree	29.39

desired angle to the ground. The upper legform impactor developed by TRL (Lawrence et al. 1991 and Hardy 1993) was used. Impactor loads, moments and acceleration were measured. The data were sampled at 10kHz and processed by means of an SAE 180 filter. Impact conditions, such as speed, impact angle and impact energy were determined from the look-up graphs defined by EEVC/WG17 (1998) and are shown in Table 2. The motion of the upper legform impactor was recorded by high-speed digital camera (1000 frames/second).

Headform-to-bonnet or window test - Figure 7 shows the headform-to-bonnet test. The headform impactor developed by TNO was used. (Philippens 1998) The acceleration of the center of gravity of the impactor was measured. The data were sampled at 10kHz and processed by means of an SAE 180 filter. The motion of the headform impactor was recorded by high-speed digital camera (1000 frames/second). The impact locations of the head impactor on the bonnet and windshield were chosen to be similar to the impact locations of the dummy head in the full-scale dummy tests. The impact angle was 65 degree, as proposed by EEVC/WG17, and the impact speed was 11.1m/s (40km/h).

Full-scale dummy tests

Figure 8 shows the full-scale dummy test. The full-scale dummy developed by Honda R&D Co., Ltd. (Akiyama et al. 2000) was used. This dummy is called Polar II and is the most advanced and biofidelic pedestrian dummy currently available. The height of the dummy is 1775 mm and the weight is 770 N. The knee ligaments are substituted by four cables connected with a system of springs and rubber tubes. The dummy was suspended from the roof in the walking posture as shown in figure 8, and released at 100 msec prior to the impact to ensure that its whole weight loads the lower extremities at the time when the vehicle cut-body hits the dummy. The dummy position was set where the left leg impacts with the center of the bumper initially at all test conditions.

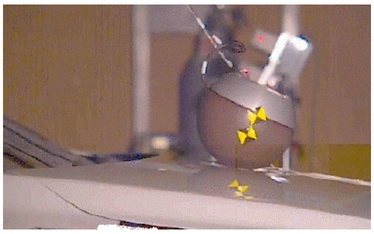


Figure 7. Headform impactor test

Figure 8. Full-scale dummy test

Measurement items – In addition to the standard instrumentation of the POLAR II dummy to measure the loads, moments and accelerations, two additional accelerometers were added to the left femur and left tibia. In order to compare the tibia acceleration of the legform impactor and the dummy, the additional accelerometer in the left tibia was added to the dummy at the location 61 mm below the knee joint center. (Though the accelerometer of the legform impactor is equipped at 66 mm below the knee joint center, the additional accelerometer of the dummy was equipped at 61 mm below due to the layout limitation.) Table 3 shows the measurement items. The data were sampled at 10kHz and processed by means of an SAE 180 filter.

Dummy Motion analysis - The motion of the dummy was recorded by high-speed digital camera (500 frames/second). To determine the dummy head impact speed, knee shearing displacement, knee

Table 3. Measurement items

Acceleration	Head, Chest, Pelvis Femur*1, Upper knee Lower knee *1, Tibia
Load cell	Upper neck, Lower neck Femur, Upper tibia Lower tibia

∗1:additional sensors

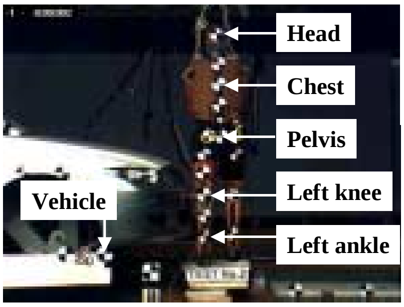


Figure 9. Target marks

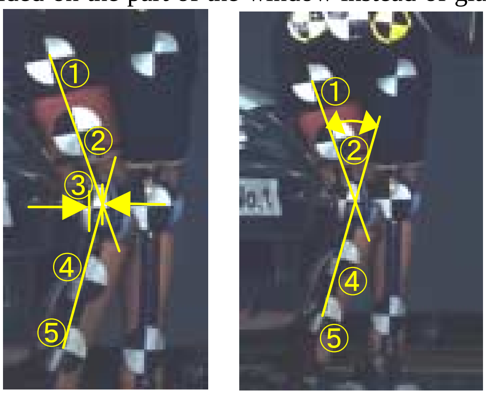
bending angle and the trajectories of some parts of the dummy, photographic targets were placed on the dummy head, torso, pelvis and lower extremities as shown in figure 9. Motion of the targets was traced and analyzed using Image Express workstation (NAC, 1995).

Head impact speed - The head impact speed was determined as the magnitude of the relative velocity between the target of the head and a car. It was assumed that the car cut-body did not move in the vertical direction because it was firmly fixed to the sled.

Knee shearing displacement and knee bending angle – Figure 10 shows the method of the motion analysis. The intersection points of the lines connecting target 1,2 and target 4,5 were calculated at each time. The knee shearing displacement was determined as the horizontal displacement between the target 3 and the intersection point. The knee bending angle was determined as the angle of the two lines. Their values were set to zero at the start of dummy-car impact.

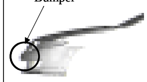
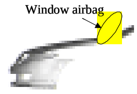
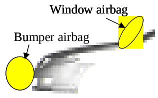
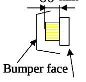
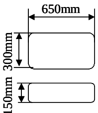
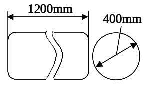
Vehicle specifications

A typical small car was used as the target car. Four types of specifications for pedestrian protection were applied as shown in table 4. To avoid the problem of the breakage of the window glass, steel panels were welded on the part of the window instead of glass. A



Shearing displacement **bending angle**
Figure 10. Method of motion analysis

Table 4. Vehicle specifications

Standard	Spec.1	Spec.2	Spec.3
	Bumper 	Window airbag 	Window airbag, Bumper airbag 
Window made by steel Without engine etc.	Energy absorbing material; 60 mm; Bumper face; Bumper reinforcement 	Window airbag Shape after deployment; 650mm; 300mm; 150mm 	Bumper airbag Shape after deployment; 1200mm; 400mm  Window airbag is sama as spec.2

50 mm urethane pad was put on the lower part of the window to avoid damage to the dummy head hardware when the window airbag is not equipped. For specification 1, an energy absorbing material was added between the bumper face and the bumper reinforcement to protect pedestrian legs. For specification 2, a window airbag was added to protect the head. The window airbag is installed under the bonnet and deploys toward the lower part of the window. The airbag covers only the center part of the window. The width is 650 mm, the length is 300 mm and the thickness is 150 mm at full deployment. For specification 3, a bumper airbag was added to increase protection to the legs. The bumper airbag is installed on the bumper face and deploys to the front of the car. The width is 1200 mm and the diameter is 400 mm at full deployment.

RESULTS

Subsystem tests

Legform-to-bumper test - Figure 11 shows the results of the standard specification, spec.1 and spec.3 for impact speed 40km/h. The maximum values of the tibia acceleration and the knee shearing displacement for spec.1 are about 30% smaller than the results for the standard specification. The knee bending angle for spec.1 is reduced as well. For spec.3, the maximum values of the above mentioned signals are reduced over 70% compared with the results of the standard specification.

Upper legform-to-bonnet leading edge test - The specification of the bonnet leading edge is only the standard specification. Figure 12 shows the results. The total load is about 6.5kN and the maximum moment is about 500Nm.

Headform-to-bonnet or window test - Figure 13 shows the results of two locations, the rear end of the bonnet and the lower part of the window. These locations coincide with the impact position of the dummy head at impact speed 25km/h and 40km/h in the full-scale dummy tests. All of the impact speeds are 40km/h. For the lower part of the window,

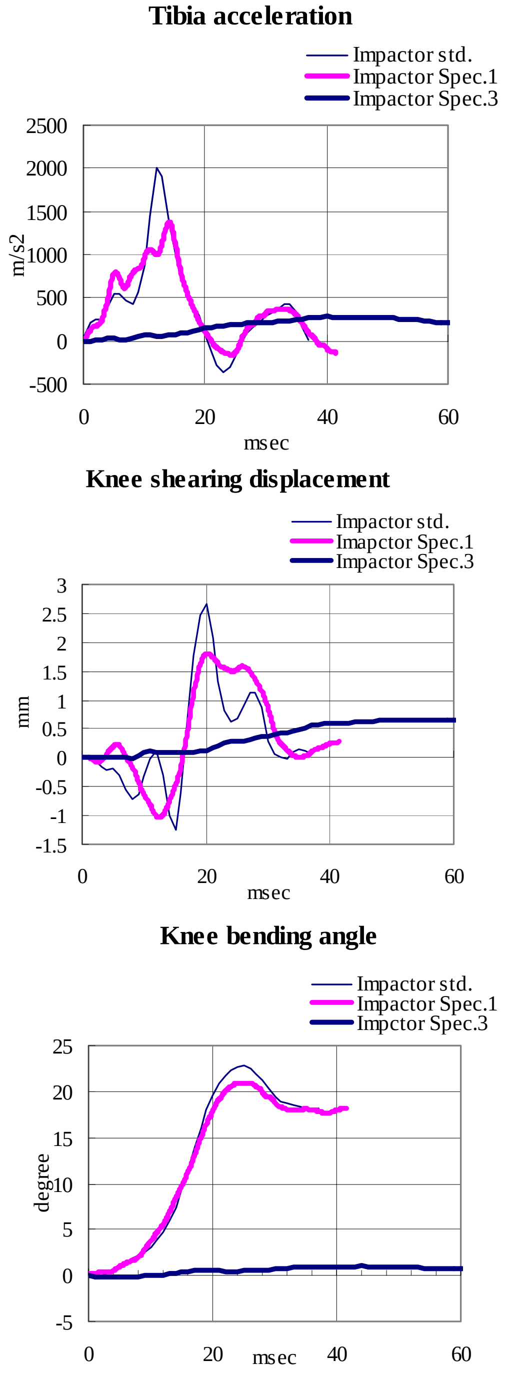


Figure 11. The comparison of standard, spec.1 and spec.3 for impact speed 40km/h

two tests with and without window airbag were conducted. Figure 14 shows the status of the impacts. The peak value of the head acceleration without window airbag for the lower part of the window is much higher than that for the rear end of the bonnet in spite of the urethane pad on the lower part of the window. By applying the window airbag the peak value of the head acceleration is reduced about 80% and the HIC value is reduced about 95%.

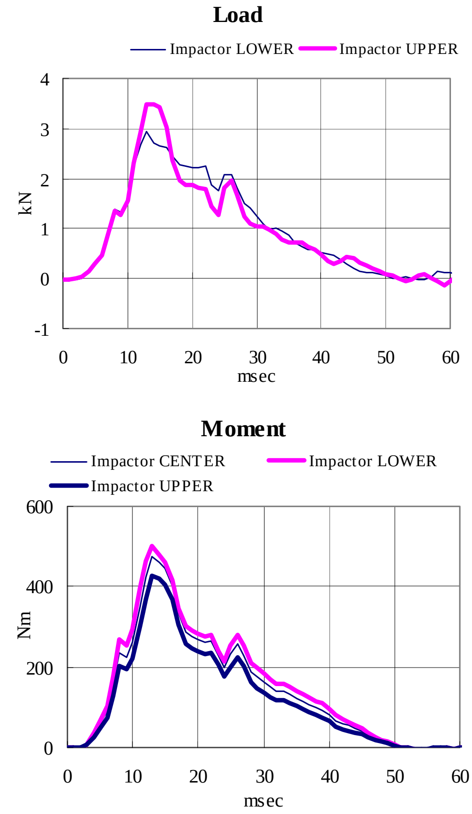


Figure 12. The results of the upper legform-to-bonnet leading edge test

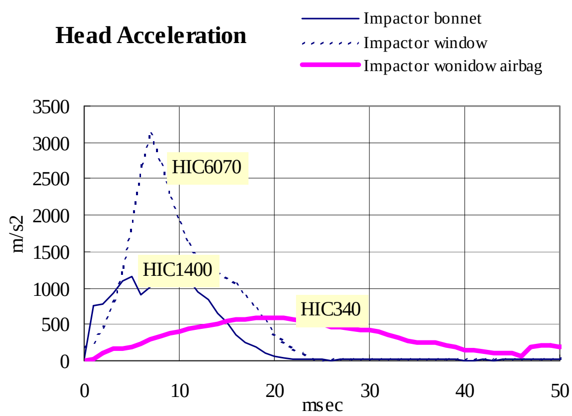


Figure 13. The results of the headform impactor tests

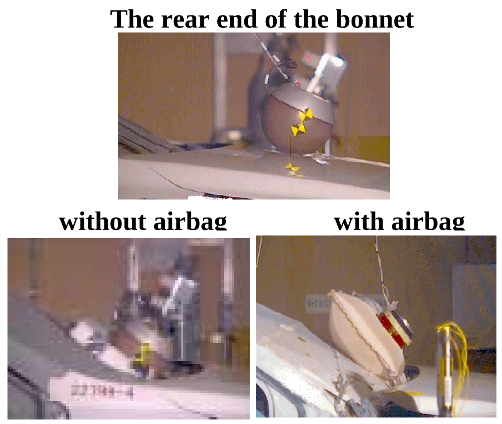


Figure 14. The impact status of headform impactor for impact speed 40km/h

Table 5. Full-scale dummy test conditions

Test No.	Test1	Test2	Test3	Test4	Test5
Impact speed km/h	25	40	←	←	←
Specification	Stan dard	←	Spec. 1	Spec. 2	Spec. 3

Full-scale dummy tests

A total of 5 tests at different impact speeds and vehicle specifications, as shown in table 5, were conducted in JARI.

__**Influence of impact speed (comparison of test 1 and 2)**__ - Comparing the results of test 1 and 2, the influence of the impact speed for the dummy responses are identified. Figure 15 shows the time histories of the accelerations of the head, chest, pelvis and tibia of the dummy. All peak values for impact speed 25km/h are reduced over 40% compared with those for 40km/h. It is also confirmed that the loads and moments of the dummy for 25km/h also tend to be reduced.

Figure 16. Knee bending angle for test 5

__**The effects of the countermeasures for leg protection**__ - Comparing the results of test 2, 3, 4 and 5, the influences of the bumper specification on the dummy responses are identified. The tibia acceleration, knee shearing displacement and knee bending angle of the dummy responses were compared to the results of the legform impactor tests.

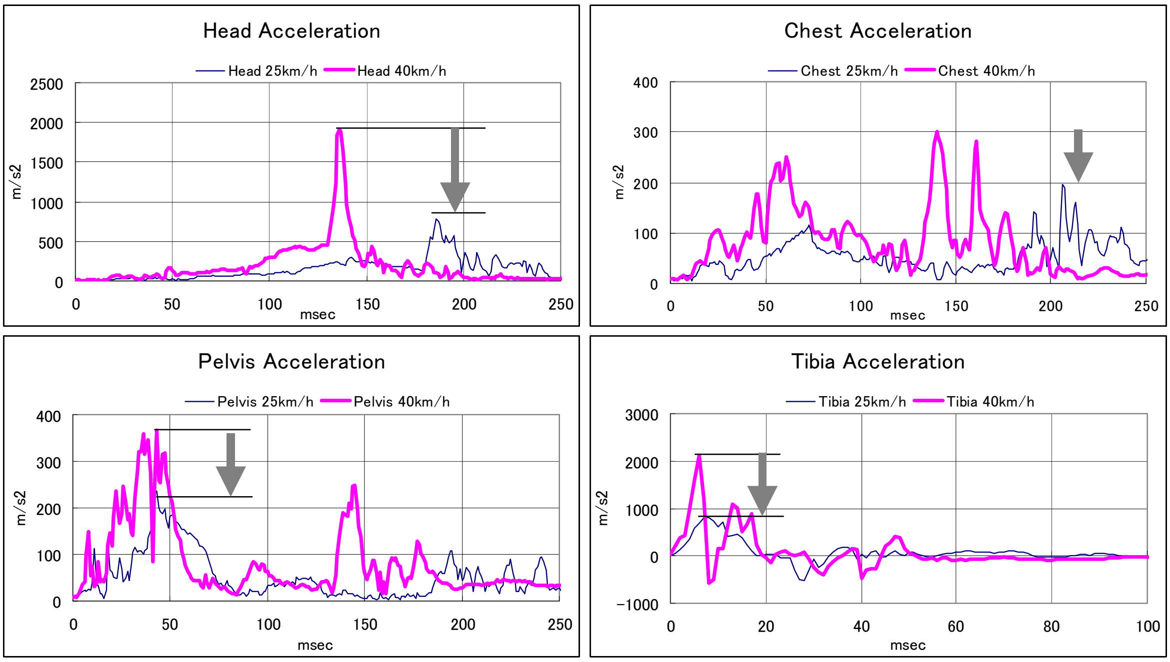


Figure 15. The acceleration time histories for impact speed 25 and 40km/h

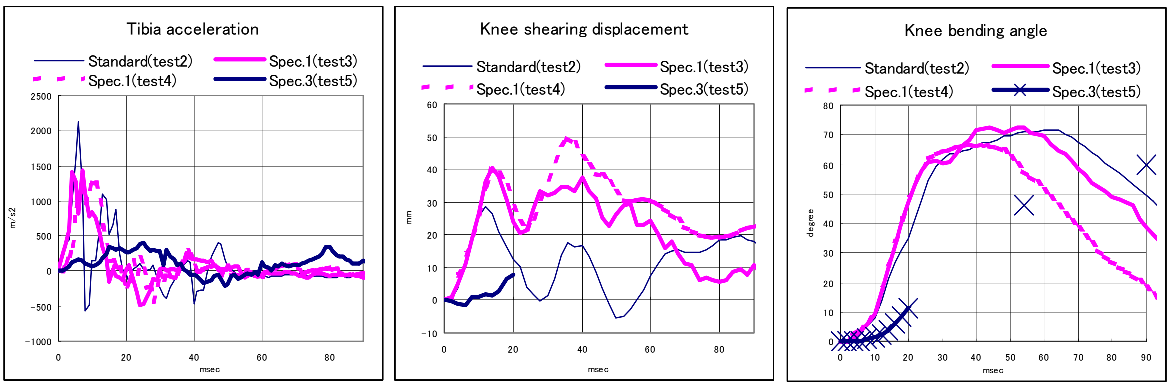
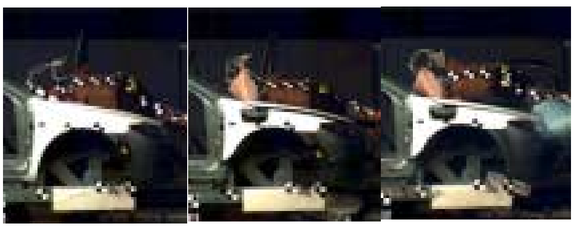


Figure 17. The results of countermeasures for leg (test 2,3,4,5)

The knee bending angle for test 5 with bumper airbag was roughly determined at 55 and 90 msec as shown in figure 16, because the target marks of the leg were concealed by the bumper airbag. Figure 17 shows the results. The peak values of the tibia accelerations for test 3 and 4 (with energy absorbing material) and 5 (with bumper airbag) are lower than for test 2 (standard). This tendency is similar to the results of the legform impactor tests. On the other hand the peak values of the knee shearing displacement for test 3 and 4 are larger than for test 2. The knee shear results for test 5 could not be analyzed because the bumper airbag concealed the dummy legs. The peak values of the knee bending angle for all of the tests are almost identical. The effect of the countermeasures could not be identified for knee shearing displacement and knee bending angle of the full-scale dummy. The methods to calculate the knee shearing displacement and knee bending angle, based on the motion analysis, cause errors because of the motions of the dummy skin and the bending deformation of the dummy legs. Therefore, these errors should be considered in future.

The effect of the countermeasure for the head (The comparison of the results of test 3, 4 and 5) - For test 4, the window airbag is applied and for test 5, the window airbag and the bumper airbag are applied. Figure 18 shows the dummy head at impact with the window (test 3) or the window airbag (test 4 and 5). Comparing the result for test 3 with those for test 4 and 5, the effect of the window airbag can be identified. Figure 19 shows the time histories of the head accelerations. Though the head accelerations for test 3 and 4 are almost the same until 110 msec, the peak acceleration at 130 msec for test 4 is much lower than for test 3. The peak time of the acceleration for test 5 is late because the start of the contact between the dummy leg and the bumper airbag which deployed forward the bumper is set to 0 msec. The peak value is much lower than for test 3. However, since the peak values for test 4 and 5 are different, the effects of the window airbag also seem to be different.



test 3 **test4** **test5**

Figure 18. Pictures at the head impact timing

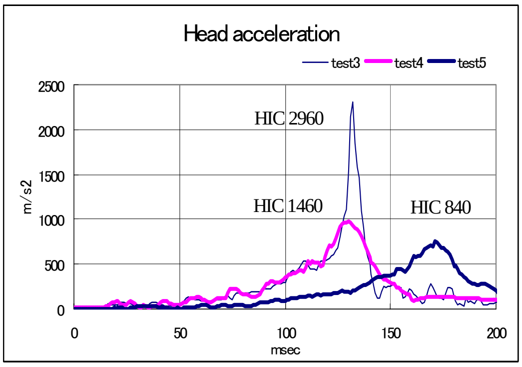


Figure 19. Head acceleration

The Comparison of the results of the subsystem tests and the full-scale dummy tests

Comparison concerning leg - Figure 20 shows the comparison of the peak values of tibia acceleration, knee shearing displacement and knee bending angle between the legform impactor and the full-scale dummy for standard, spec.1(with energy absorbing material) and spec.3(with bumper airbag). The peak values of tibia accelerations for the legform impactor tests are similar to the full-scale dummy tests. And the trends of the differences between the specifications are similar as well. The values of the knee shearing displacement and knee bending angle for full-scale dummy tests are much larger than for legform impactor tests. For legform impactor tests, peak of spec.3 show a large decrease compared with spe.1 and 2. However, such a phenomenon is not found for the full-scale dummy tests.

The comparison concerning upper leg – The same specification of the bonnet leading edge is

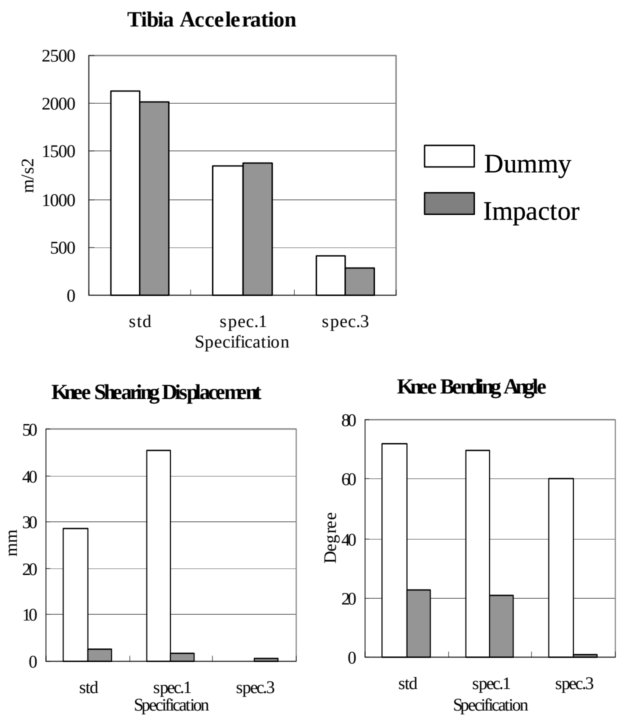


Fig.20. The comparison of dummy and impactor for the evaluation of leg

applied for test 3-5 of the full-scale dummy tests. But the stiffness of test 4 and 5 may be changed a little because of the setting of the window airbag. Therefore the results of test 3 were compared with the results of the upper legform impactor test. For the impactor test, the loads and moments proposed by EEVC/WG17 were used. In the dummy test the lateral load and moment from load cell located at 210 mm above the center of the knee joint in the left femur and the accelerations from an accelerometer located at 165 mm above the center of the knee joint were used for comparison. Figure 21 shows the time histories. The peak acceleration of the dummy is close to that of the impactor. However, the shapes of the time histories of the loads and moments are considerably different.

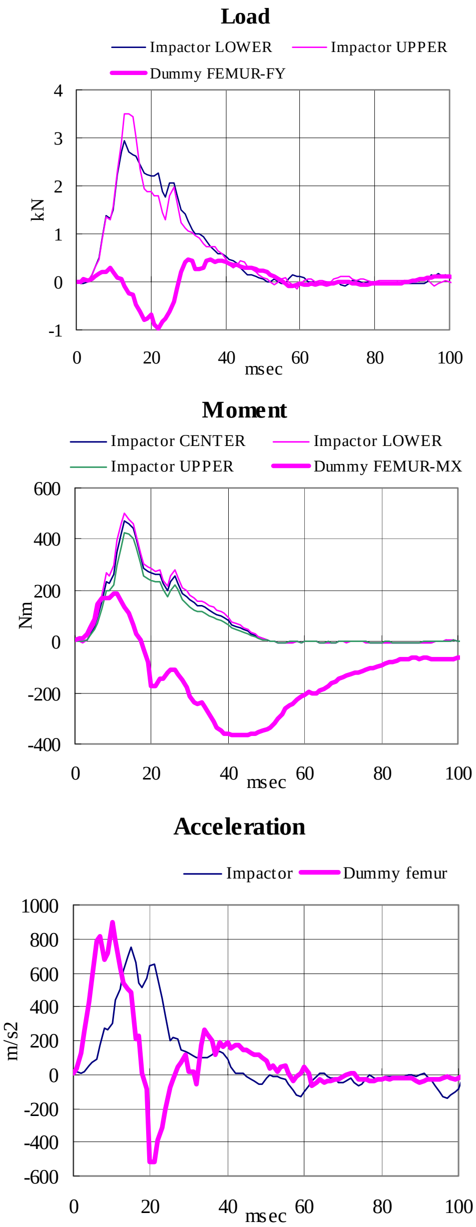


Figure 21. The comparison of dummy and impactor for the evaluation of upper leg

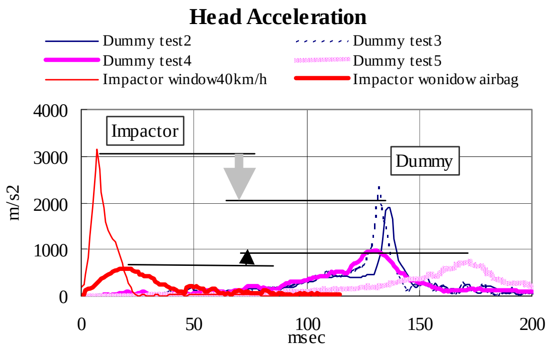


Figure 22. The comparison of dummy and impactor for the evaluation of head

<u>The comparison concerning head</u> - Figure 22 shows the time histories of the accelerations of the dummy head and the headform impactor for 40km/h. The impact location is on the lower part of the window. The results of the tests with and without window airbag are shown. In the dummy tests, the results of test 2 and 3 were used for the results without window airbag and the results of test 4 and 5 were used for the results with window airbag. In the case without airbag the peak values of the accelerations for the dummy tests are lower than those for the impactor tests. On the other hand in the case with airbag the peak values for the dummy tests are higher.

DISCUSSION

The causes of the differences between subsystem tests and full-scale dummy tests

<u>The differences for leg</u> - Figure 23 shows the motions of the impactor and the dummy leg for vehicle specification 1 (with energy absorbing material). From the left side in this figure, the each motion at the time of the peak of the tibia accelerations, the knee shearing displacement and the knee bending angle are shown. Since the time of the peak of the tibia acceleration occurs at a very early stage in the impact, the upper body of the dummy hardly moves with respect to the legs. Therefore, the inertia does not influence the peak value. And this explains the similar peak values of the tibia accelerations. The knee bending angle of the legform impactor decreases after 25 msec because both the femur and the tibia start to rebound. The knee bending angle of the dummy leg increases until 50 msec. It is assumed that this phenomenon is caused by the inertia of the upper body of the dummy and the friction between the dummy feet and the ground. This phenomenon also might cause the difference concerning the knee shearing displacement. However, the reason could not be identified from the test

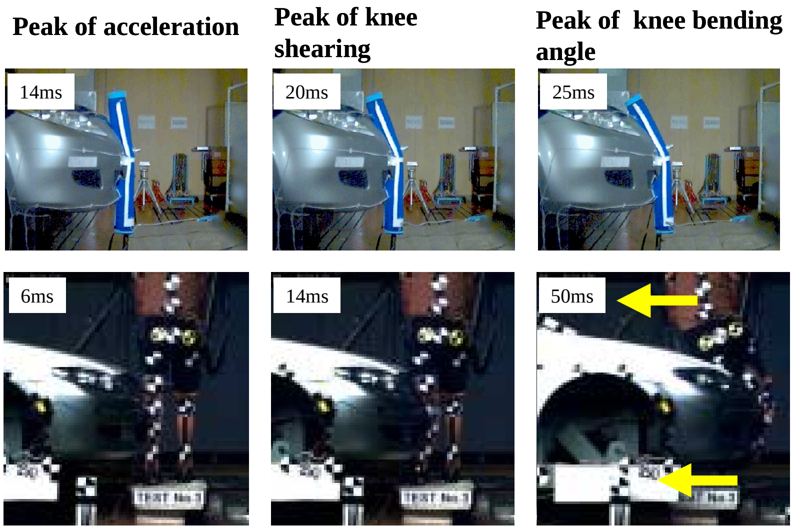


Figure 23. The comparison of dummy and impactor for the evaluation of leg

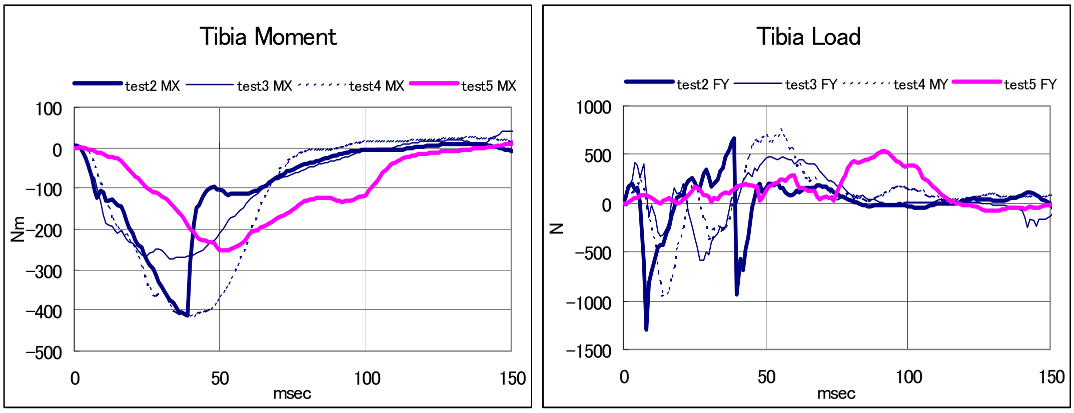


Figure 24. The load and moment of the tibia (test 2, 3, 4, 5)

results, because the results of the knee shearing displacement are not reliable due to the limitation of the motion analysis. It seems to be difficult to evaluate the leg protection performance using the knee shearing displacement and bending angle of the dummy leg. Because the differences of these values in the full-scale dummy tests can not be observed clearly among the several vehicle specifications, and some errors and variations are included in the motion analysis.

The lateral loads and bending moments by a load cell installed in the dummy tibia were evaluated as an alternative method. Figure 24 shows the results of test 2, 3, 4 and 5. The load and moment in the test 2 are sharply decreased at about 40 msec. When the dummy was checked after test 2, it was confirmed that a cable representing the ligament inside the left knee was broken. Though the bumper specification of test 3 is the same as that of test 4, the loads and moments are different. The reason of this difference could not be identified because of the limitation of the number of the tests. The moment and load of test 5 are similar as those of test 3. It is concluded from the results that the bumper airbag used in this test can not reduce the risk of the injury caused by knee bending and shearing. As mentioned above it seems to be possible to evaluate the leg injuries by the load and moment of the dummy tibia.

<u>The differences for upper leg</u> - Figure 25 shows the time histories of the loads, moments and accelerations of the dummy femur for test 4 and 5. The peak values for test 5 are much lower than for test 4.

However the evaluation results of both of the tests using the legform impactor must be the same because the specification of the bonnet leading edge in the test 5 is the same as that in the test 4. Why were the peak values in the test 5 using the full-scale dummy reduced? Figure 26 shows a picture at 50 msec in the test 5. The bumper airbag is moved upward by the movement of the dummy and covers the bonnet leading edge. This phenomenon seems to have caused the reduction of the peak values in the test 5. The full-scale dummy test is necessary to evaluate such effects because the impactor test can not evaluate such phenomena.

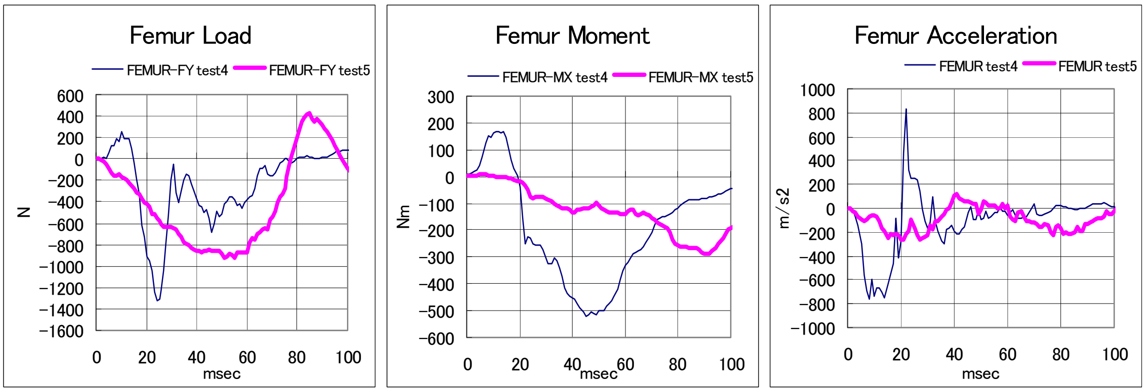


Figure 25. The loads, moments and accelerations of the femur for test 4 and 5

Figure 26. Picture at 50 msec for test 5

<u>**The differences for head**</u> - In the cases without airbag, the peak values of the accelerations of the dummy head are lower than those of the headform impactor. On the contrary, in the case with airbag, the peak values of the dummy head are higher. Figure 27 shows two pictures at the time when the dummy head began to impact against the window or the window airbag for test 3 and 4. In the case without airbag, there is no space between the dummy chest and the bonnet when the head begins to impact against the window. Therefore, the movement of the chest does not influence the movement of the head. This is the same condition as the headform impactor test. In the case with airbag, there is some space between the dummy chest and the bonnet when the head begins to impact against the window airbag. It is assumed that the window airbag absorbs a part of the kinetic energy of the chest in addition to the head. This phenomenon seems to be a reason that the peak head acceleration in the dummy test is larger than that in the impactor test. Figure 28 shows the time histories of the relative velocity between the head and the car for all of the dummy tests. The impact timings between the head and the window or the window airbag are shown as ● marks in the figure. The impact speed of test 4 and 5 with the window airbag is 12.8 m/s and 12.5 m/s, higher than the impact speed for the impactor test(11.1 m/s). This seems to be another reason. The impact speed of test 2 and 3 without the window airbag is 9.8 m/s and 11.1 m/s, the same or lower than the impact speed of the impactor test(11.1 m/s(40km/h)). This difference of impact speed seems to cause that the peak value of the dummy head acceleration is lower than that of the impactor acceleration in the test without window airbag. Therefore, the impact speed of the full-scale dummy head should be considered for the evaluation of countermeasures for head protection. For the evaluation of window airbags the full-scale dummy test is necessary because the upper body of the dummy influences the performance of the window airbag.

The effects of the countermeasures for pedestrian protection

In this research project, an energy absorbing material inside the bumper, a window airbag and a bumper airbag were applied as the countermeasures for

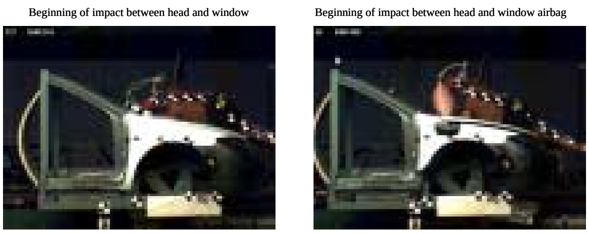


Figure 27. The pictures of the impact between the dummy head and the window or the window airbag

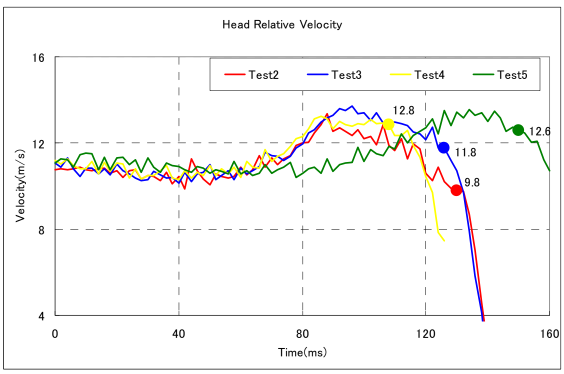


Figure 28. The relative velocities for the full-scale dummy tests

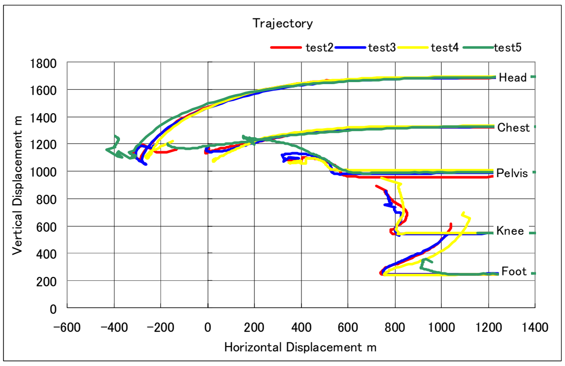


Figure 29. The trajectory of each part of the dummy relative to the car

pedestrian protection. It was confirmed by the impactor tests and the full-scale dummy tests that these countermeasures are effective. However the magnitude of the effects is different for the impactor and full-scale dummy tests. The energy absorbing material inside the bumper is only effective for leg protection, the window airbag is effective for head protection and the bumper airbag is effective for leg and upper leg protection. Figure 29 shows the trajectories of the head, chest, pelvis, knee and foot for test 2, 3, 4 and 5. The trajectories for all tests except test 5 are almost identical. It was also confirmed, from the results of the other measurements, that the applied countermeasures did not give any bad influences to other body parts. For test 5 (with the bumper airbag), the pelvis moves more upwards and the horizontal displacement of the head is a bit longer than for the other tests. However, it is confirmed that the differences of the movements do not give any bad influences to the results of the other parts. On the contrary, it is confirmed that the load, moment and acceleration of the dummy femur are reduced by the upward movement of the pelvis. Therefore not only the impactor tests but also the full-scale dummy tests are necessary to design and evaluate the countermeasures like window airbag and bumper airbag. The window airbag and bumper airbag are very effective methods to improve the performance of pedestrian protection in the limited space to achieve the miniaturization of vehicle size and good visibility. However, it is necessary to detect or predict the collision between a vehicle and a pedestrian with high reliability in order to implement these countermeasures. Some researches concerning such sensing system have been reported. (P.N. Holding 2001)

CONCLUSIONS

EEVC subsystem tests (impactor tests) and full-scale dummy tests were conducted to evaluate four kinds of vehicle specifications for a compact car. The following conclusions were made by comparing the results of two types of tests.

The differences between EEVC subsystem tests and full-scale dummy tests

Leg - The peak values of the tibia accelerations for the dummy tests are identical to the legform impactor tests for the every specification. It is assumed that the inertia of the upper body of the dummy does not influence the acceleration, since the peak occurs at an early stage in the impact. The knee shearing displacement and knee bending angle for the full-scale dummy tests are much larger than those for the impactor tests because of the inertia of the upper body of the dummy and the friction between the feet and the ground. These signals are not suitable to evaluate the risks of the leg injuries because they do not represent the differences of the vehicle specifications and have errors and large variations. It is possible to evaluate the risk of injuries caused by knee shearing and bending using the lateral load and moment measured by the load cell installed in the dummy tibia for the full-scale dummy test.

Upper leg - The full-scale dummy test is necessary to evaluate the upper leg protection because the loads and moments of the dummy femur affected by the different movement of the dummy caused by the different specification of the bumper.

Head - For the specification without the window airbag, the peak value of the acceleration of the dummy head is lower than that of the headform impactor because the impact speed of the dummy head is lower than the vehicle speed.
For the specification with the window airbag the peak value of the acceleration of the dummy head is higher than that of the headform impactor because the impact speed of the dummy head is higher than the vehicle speed and the movement of the upper body of the dummy influences the performance of the airbag.

The countermeasures for pedestrian protection

In this research an energy absorbing material inside the bumper, a window airbag and a bumper airbag were applied as the countermeasures for pedestrian protection. It was confirmed by both of the impactor tests and the full-scale dummy tests that these countermeasures are effective though the magnitude of the effects are different between these tests.
The energy absorbing material inside the bumper is effective for only leg protection, the window airbag is effective for head protection and the bumper airbag is effective for leg and upper leg protection.
Not only the impactor tests, but also the full-scale

dummy tests are necessary to design and evaluate the countermeasures like window airbag and bumper airbag because their performance strongly influences the movement of the dummy.

ACKNOWLEDGMENTS
The authors thank Honda R&D Co., Ltd. for generously providing the Polar dummy and assisting in the full-scale dummy experiments and thank Japan Automobile Research Institute (JARI) for conducting the full-scale dummy tests.

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